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PROJECT APOLLO

A PRELIMINARY INVESTIGATION OF SYSTEM REQUIREMENTS TO LIMIT VEHICLE OVERPRESSURES ABORTING FROM AN EXPLODING BOOSTER AT DYNAMIC PRESSURES IN EXCESS OF 500 POUNDS PER SQUARE FOOT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Prepared by: Richard C. Kennedy

Richard C. Kennedy
AST, Fluid Mechanics

Authorized for Distribution:

Robert R. Gilruth

Robert R. Gilruth, Director

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SUMMARY

Presented herein are preliminary results of studies of separation requirements applicable to aborts at dynamic pressures between 500 pounds per square foot and 2,000 pounds per square foot. Booster-capsule separation criterion was based upon the limiting of excessive overpressures due to a booster detonation. Abort warning time requirements are presented as functions of separation acceleration and explosion overpressure. Deceleration levels experienced by the representative abort configuration after rocket motor burnout are presented for a range of burning times and separation accelerations.

Results of drag-free calculations which provide for the estimation of trajectory conditions at maximum dynamic pressure as a function of launch thrust-to-weight ratio are also included.

INTRODUCTION

The purpose of this paper is to present results of preliminary studies of conditions and criteria applicable to the performance of suborbital or atmospheric abort systems.

Initial conditions at abort were determined for a launch vehicle system with an assumed specific impulse of 245 seconds. The investigation was then concerned with abort system performance at $\bar{q}_{max}$ values in excess of 500 pounds per square foot (psf). Primary attention was given to:

(a) Providing sufficient separation distance between a nonthrusting booster and capsule to escape damage from a booster explosion.

(b) Thrust requirements to provide for (a) above.

(c) Decelerations experienced after abort motor burnout.

SYMBOLS

C_D	drag coefficient, $\frac{\text{Drag force}}{qS}$
D	drag, lb
g	acceleration of gravity, ft/sec^2
h	altitude, ft
I_s	fuel specific impulse, sec
M_o	mass at launch, slug
M_f	mass of fuel at end of burning, slug
M	Mach number
q	dynamic pressure, psf
S	reference area, ft^2
T	thrust, lb
t_b	burning time at constant thrust, sec
t_w	warning time (time between abort thrust initiation and booster detonation), sec
V	velocity, ft/sec
W	weight, lb

Subscripts

Abort	abort configuration
L	booster launch
$\bar{q}_{max}$	value at maximum $\bar{q}$

PROCEDURE

Detonation overpressure data used in this investigation are based upon a stationary, sea-level reference explosion of 1 kiloton TNT yield $\left(W_o\right)$. Distance time histories of shocks resulting from a lesser yield (W) were found by cube-root scaling laws as per reference 1. For a shock of given overpressure:

$$d = d_o\left(\frac{W}{W_o}\right)^{\frac{1}{3}}\left(\frac{p}{p_o}\right)^{\frac{1}{3}}$$

(Subscript "o" refers to reference explosion)

$$t = t_o\left(\frac{W}{W_o}\right)^{\frac{1}{3}}\left(\frac{p}{p_o}\right)^{\frac{1}{3}}\left(\frac{T_o}{T}\right)^{\frac{1}{2}}$$

where

d = distance from explosion, ft

t = time of arrival of shock at d, sec

p = atmospheric pressure at explosion altitude, psf

T = atmospheric temperature, ^{o}R

In order to determine overpressures a vehicle would experience in the vicinity of a booster explosion, off-the-pad and $\bar{q}_{max}$ abort trajectories were computed on an IBM 704 digital computer for a point mass body with characteristics as listed in table I. The vehicle trajectories were then superimposed upon the shock distance time histories to determine warning time requirements as a function of shock overpressure.

In order to estimate initial conditions for $\bar{q}_{max}$ aborts, trajectory calculations were made, assuming constant thrust, in a drag-free environment. This provided velocity and altitude as a function of I_s, t_b, and $\left(\frac{T}{W}\right)_L$. Dynamic pressure was found using a density-altitude variation consistent with a polytropic atmosphere of exponential 1.235 $\left(\text{i.e., } pv^{1.235} = k\right)$. Sea-level density was 2.378×10^{-3} slug/ft^3. For the altitude range considered, this variation agrees to within 0.3 percent of values to reference 2.

The subject calculations resulted in the following expressions:

(1) $V = -32.2 \left[I_s \ln K_1 + t \right]$

(2) $h = 32.2 \left\{ \dfrac{\left(I_s\right)^2}{\left(\frac{T}{W}\right)_L} \left[K_1 \ln K_1 + 1 - K_1 \right] - \dfrac{t^2}{2} \right\}$

(3) $\bar{q} = K_2 \left[I_s \ln K_1 + t \right]^2 \left\{ 1 - K_3 \left[\dfrac{\left(I_s\right)^2}{\left(\frac{T}{W}\right)_L} \left(K_1 \ln K_1 + 1 - K_1 \right) - \dfrac{t^2}{2} \right] \right\}^{4.255}$

where

$$K_1 = 1 - \frac{\left(\frac{T}{W}\right)_L t}{I_s}$$

$$K_2 = 1.238$$

$$K_3 = 0.22138 \times 10^{-3}$$

Equation (3) was solved for time to $\bar{q}_{max}$ as a function of $\left(\frac{T}{W}\right)_L$. $V_{\bar{q}_{max}}$ and $h_{\bar{q}_{max}}$ were then found from equations (1) and (2) respectively.

Figures 1 and 2 show the results of these calculations with $I_s = 245$ seconds for various $\left(\frac{T}{W}\right)_L$.

The accuracy of the calculations is indicated in figure 3 which shows velocity and altitude (calculated from equations (1) and (2) at first-stage burnout of a launch system currently under investigation).

The symbols indicate values obtained from an IBM 704 trajectory computation. It is seen that the drag-free calculations of velocity and altitude agree to within 2 percent and 9 percent respectively, of machine-computed values.

DISCUSSION OF RESULTS

Figure 4 represents warning time as a function of overpressure and $\left(\frac{T}{W}\right)_{abort}$ for off-the-pad aborts. For example, if a booster of 1,000,000-lb fuel detonates with a reactive equivalence of 0.5 TNT (yield = 500,000 lb), a capsule of $\left(\frac{T}{W}\right)_{abort} = 15$ would require 1.2 seconds warning time to limit the overpressure to 20 pounds per square inch (psi). As indicated, the range of yields considered does not affect warning time requirements appreciably.

The scaling of explosions to a nominal altitude of 35,000 feet for $\bar{q}_{max}$ and comparison with abort trajectories at $\bar{q}_{max}$ showed altitude to have a negligible effect on warning time requirements for a given separation acceleration.

The magnitude of decelerations encountered after abort motor burnout for the reference configuration is shown in figure 5. This figure, in conjunction with figure 4, provides an estimate of deceleration in relation to overpressure for a design separation acceleration. Considering burning time equal to warning time, a vehicle with an overpressure capability of 10 psi and a design separation acceleration of 15g, a burning time (warning time) of approximately 1.5 seconds would be required and would result in an 11g deceleration after abort at 1,000 psf. However, a thrust level to provide a 15g separation acceleration at $\bar{q}_{max} = 1{,}000$ psf, would result in a value of $\left(\frac{T}{W}\right)_{abort} = 22.2$ for an off-the-pad abort.

The trajectory calculations of the previous sections have been extended to indicate thrusting accelerations experienced on a typical booster trajectory as a function of $\left(\frac{T}{W}\right)_L$ and burning time. This result is shown in figure 6. The line marked "$\bar{q}_{max}$" indicates burning time required to achieve $\bar{q}_{max}$ and percent of system fuel consumed at this time.

CONCLUSIONS

Based on the foregoing results, it is concluded that:

(a) Booster explosion yields in the range of 250,000-lb to 1,000,000-lb equivalent TNT do not greatly affect warning time requirements for a given overpressure and separation acceleration.

(b) Altitude at $\bar{q}_{max}$ has a negligible affect on warning time; off-the-pad warning time requirements can be considered as design values for launch systems resulting in $\bar{q}_{max}$ values as high as 2,000 psf.

(c) Thrust requirements for aborts at $\bar{q}_{max}$ between 500 and 2,000 psf designed on the basis of escaping excessive booster detonation overpressures will exceed those at sea level by an amount necessary to overcome initial drag on the abort configuration.

(d) Drag-free trajectory calculations can provide sufficiently accurate results to be useful in preliminary studies of large booster systems.

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1. Minzner, R. A., Champion, K. S. W., and Pond, H. L.: The ARDC Model Atmosphere, 1959. Air Force Surveys in Geophysics No. 115 (AFCRC-TR-59-267), Air Force Cambridge Res. Center, Aug. 1959.

2. Thornhill, C. K.: Explosions in Air. Armament Research and Development Establishment (The War Office), Kent, England, A.R.D.E. Memo. (B)57/60, Sept. 1960.

TABLE I.- ABORT CONFIGURATION DATA

W	12,000 lb
C_D	0.65 (Constant)
S	132 ft^2
I_s	245 sec
Thrust onset rate	10^6 lb/sec
Thrust tail-off rate	2×10^5 lb/sec
$\left(\frac{T}{W}\right)_{abort}$ (off-the-pad)	parameter
$\left(\frac{T - D_{q_{max}}}{W}\right)_{q_{max}}$	parameter
t_b	parameter

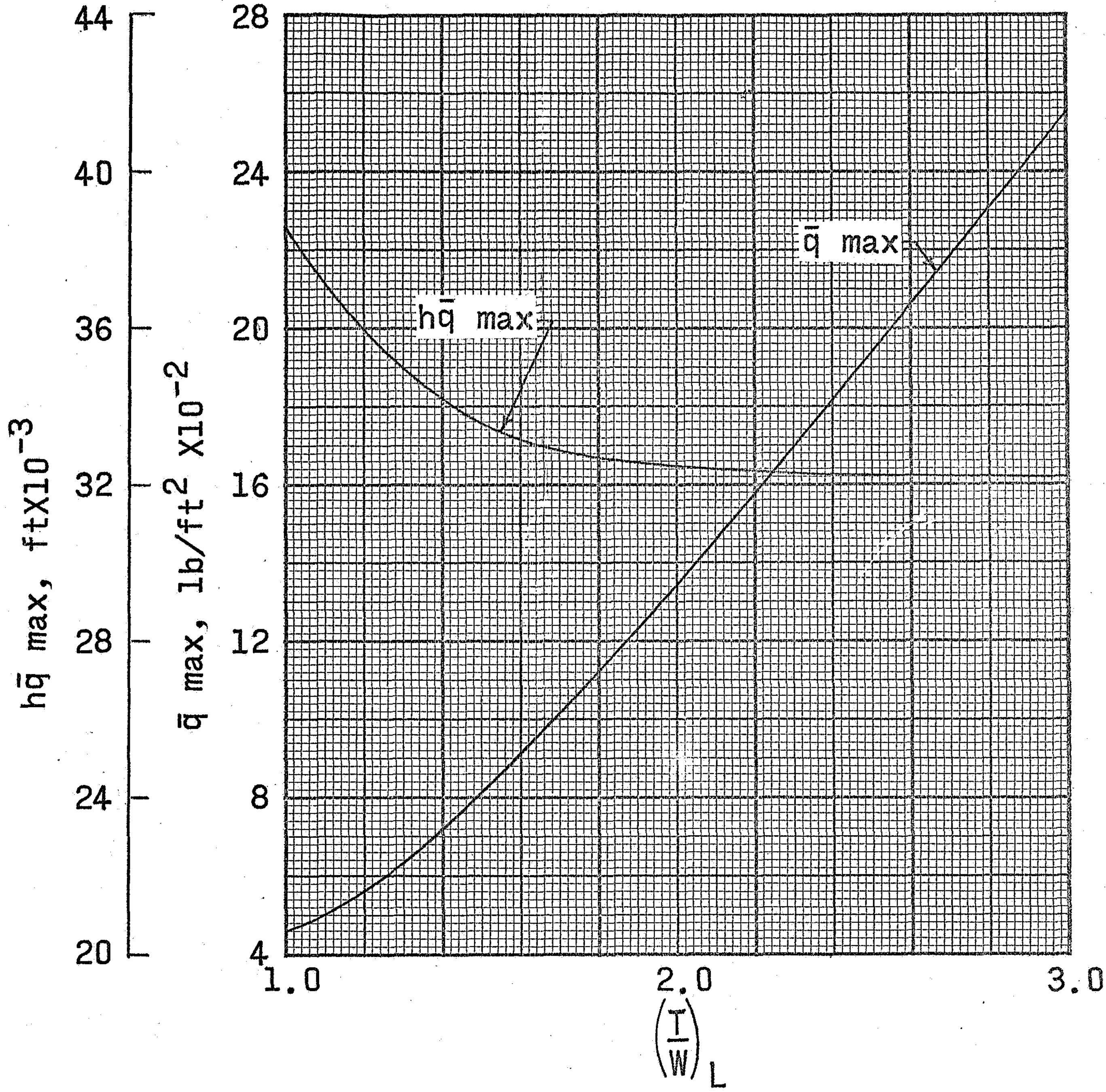


Figure 1.- $\bar{q}$ max and altitude for $\bar{q}$ max vs. $(T/W)_L$. I_s = 245 sec.

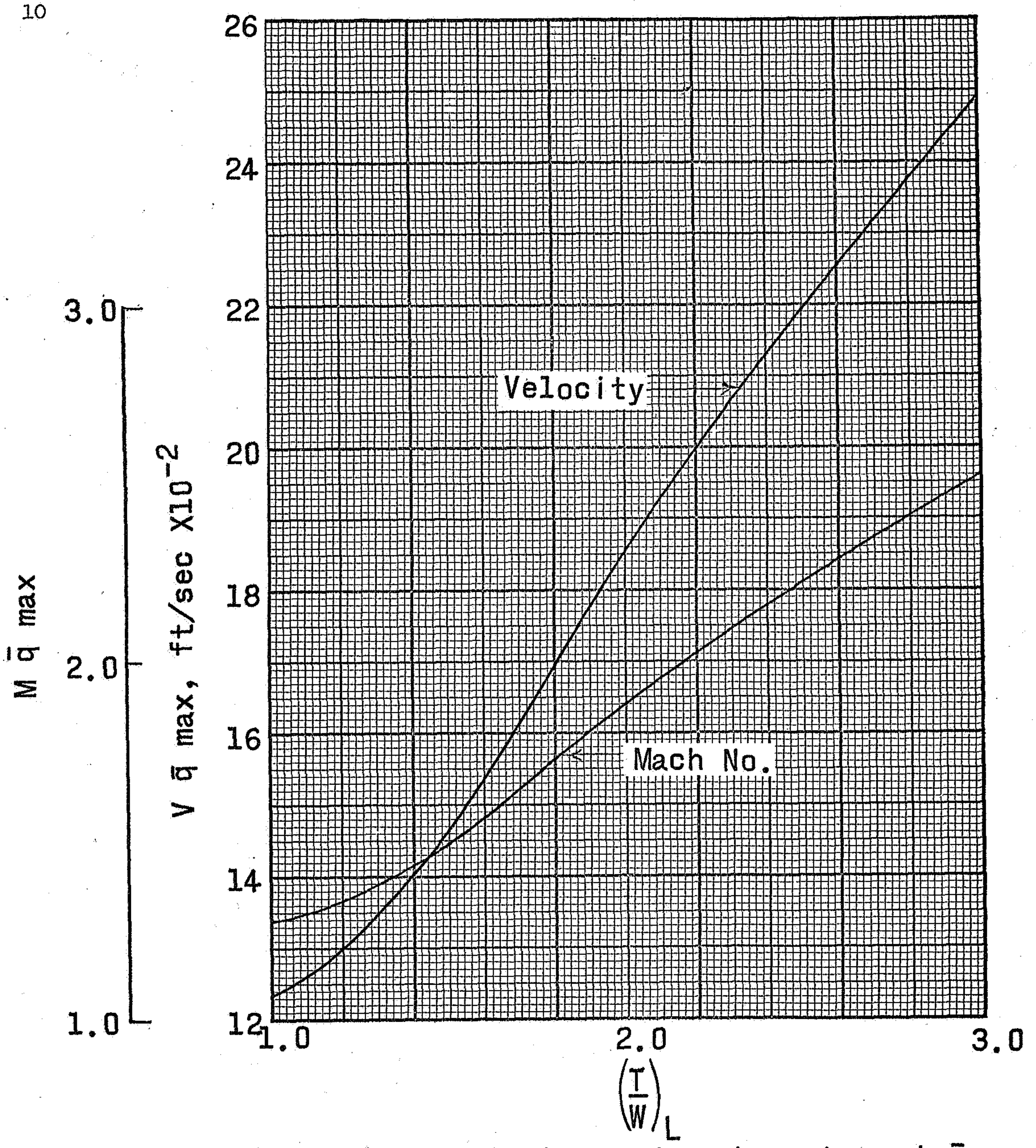


Figure 2.- Velocity and mach number at $\bar{q}$ max vs $(T/W)_L$. I_s = 245 sec.

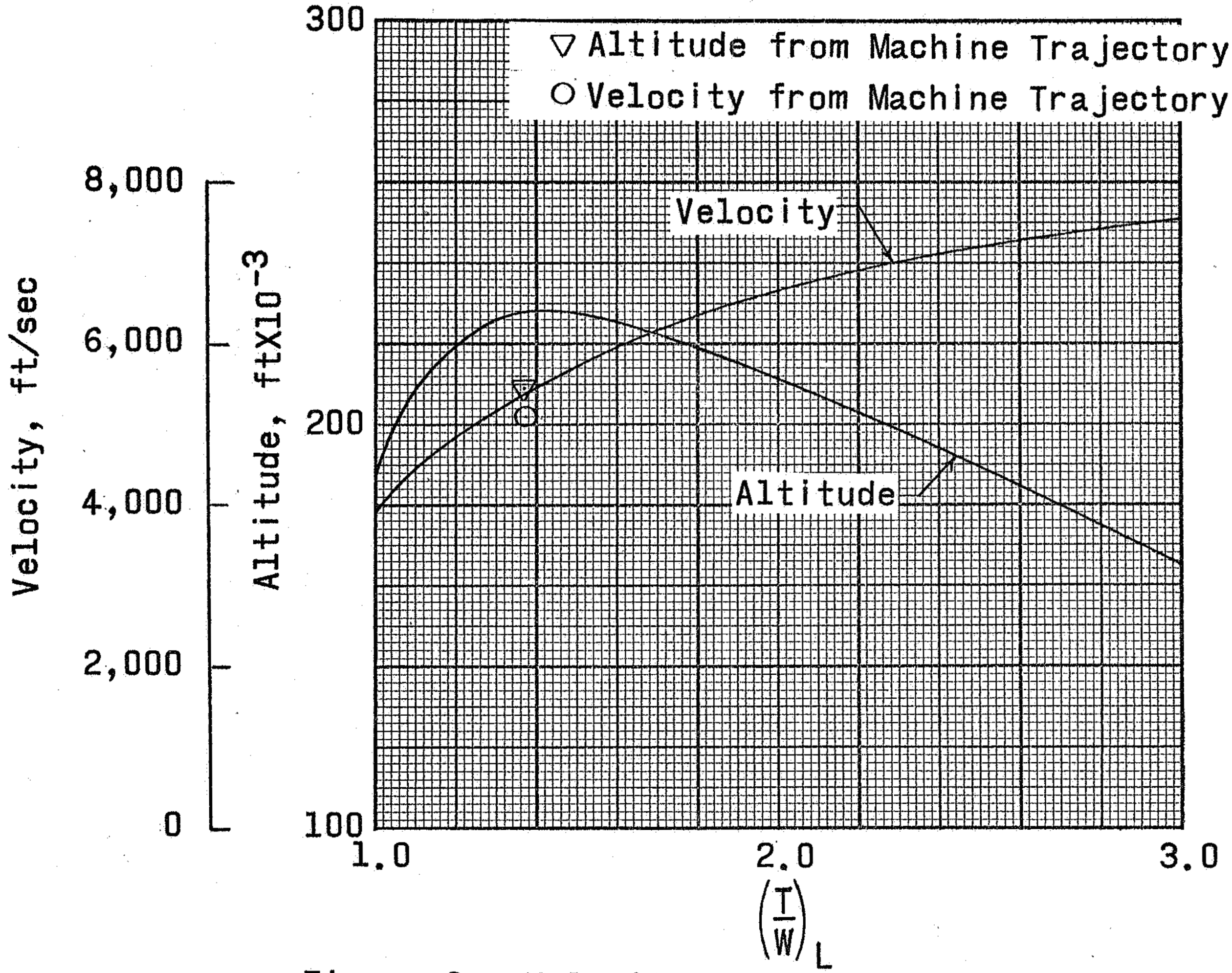
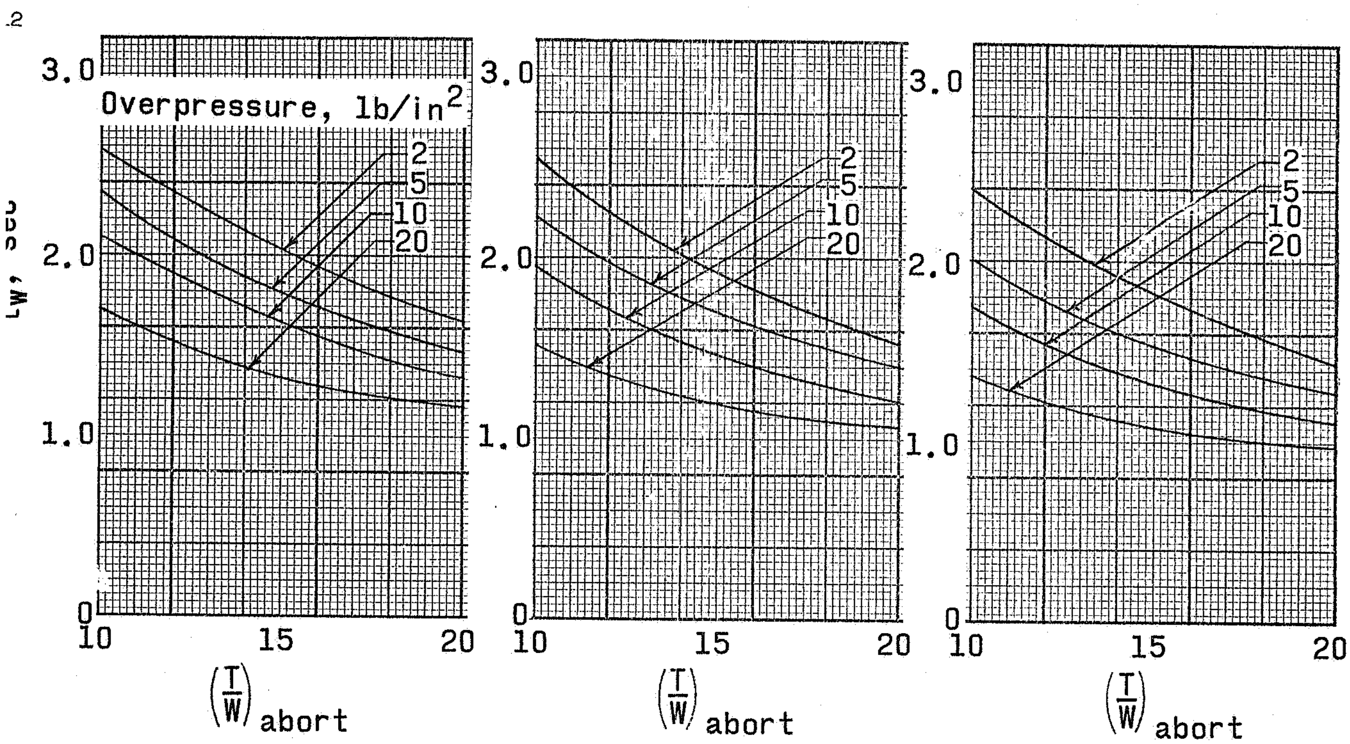


Figure 3.- Velocity and altitude at first-stage burnout vs $(T/W)_L$. $I_s = 245$ sec.



(a) Yield= 1,000,000 lb (b) Yield= 500,000 lb (c) Yield= 250,000 lb

Figure 4.- Warning time required vs (T/W) abort for various overpressures. Sea level detonation. I_s = 245 sec.

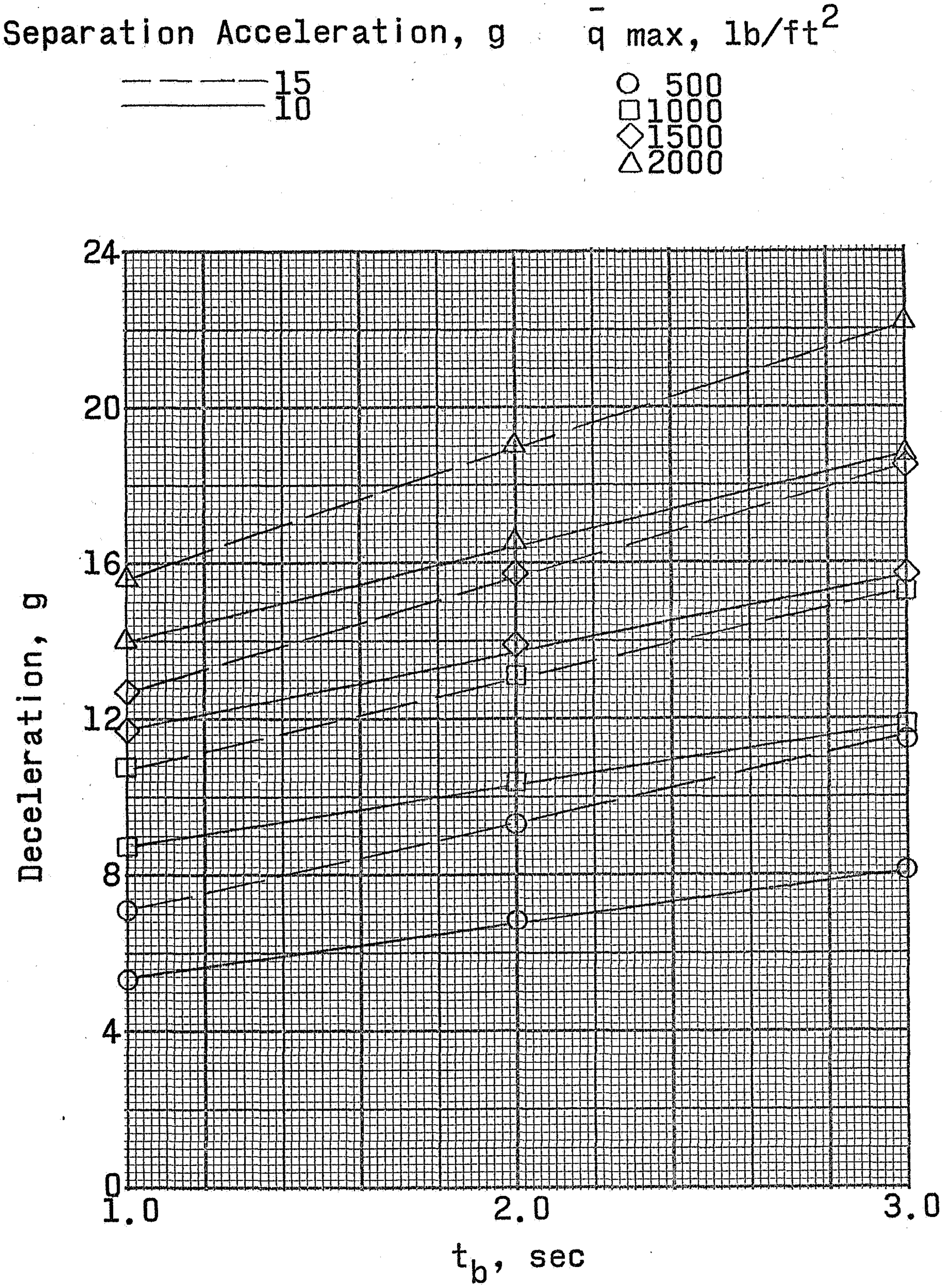


Figure 5.- Deceleration vs t_b for various $\bar{q}$ max and separation accelerations. I_s = 245 sec.

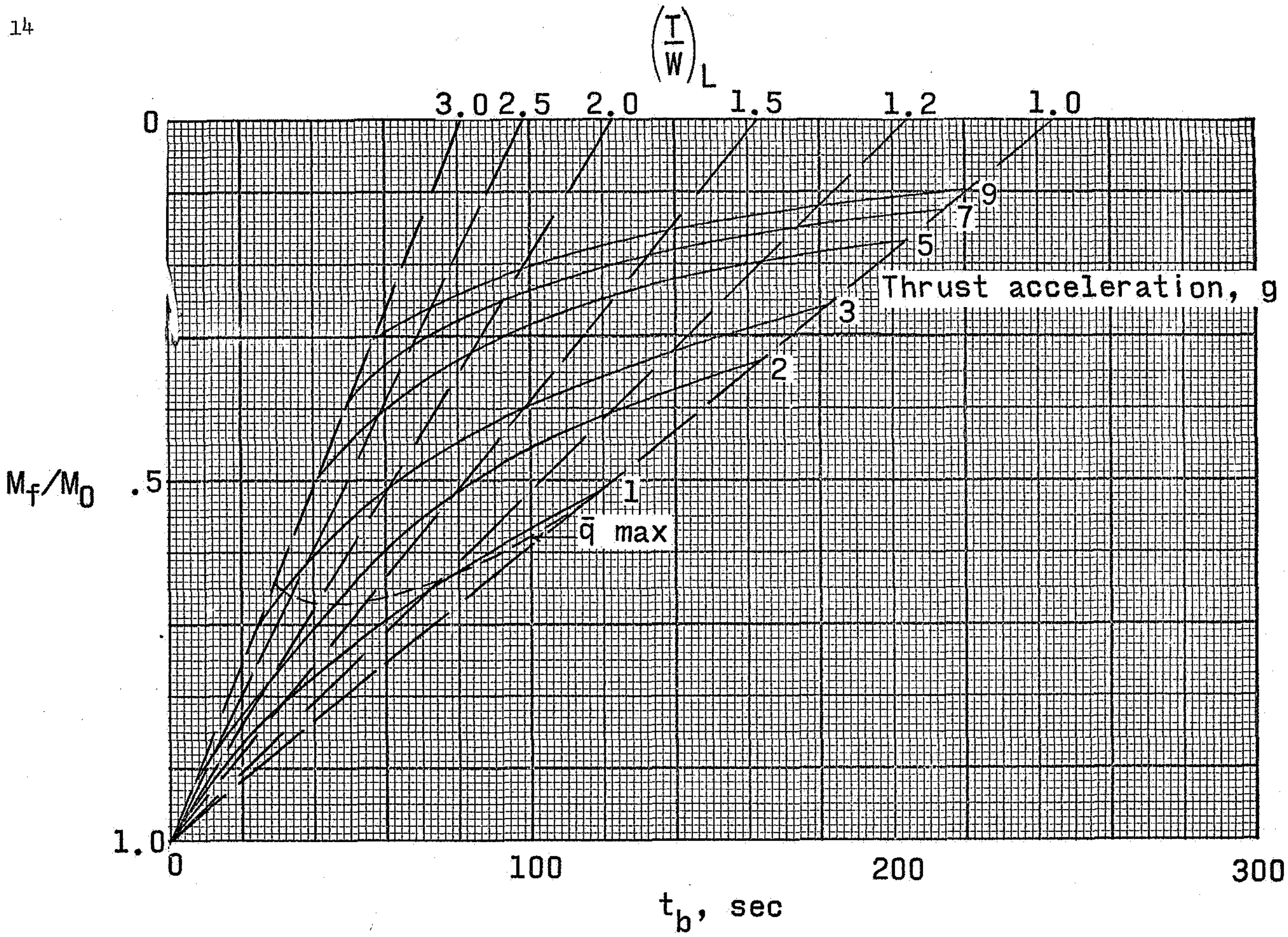


Figure 6.- Thrust acceleration as function of $(T/W)_L$ and t_b. I_s = 245 sec.